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14. ABSTRACT
The grant supported research effort to understand factors limiting current-carrying capabilities in coated conductors (CCs). Three new operating modes of scanning laser microscopy (SLM) were developed under this grant, and total of five SLM modes were utilized for the research. The research found that the increased local-current density (current-crowding) was the main cause for the dissipation and the limiting factor for the current-carrying capacity. It was found in striated CCs that the current-crowding was caused by scratches from sample-handling, localized damages during striation process, or current flow configuration due to specific striation patterns. The other aspect of the research was to understand superconducting dissipation from various YBCO-family films on bicrystal grain boundary (GB) junctions. The samples on 24° [100]-tilt GB showed that the dissipation appeared like "hot-spots" along GB. There was no significant difference in the size and/or the pattern of hot-spots for different YBCO-family samples (regardless of nanoparticle additions, doping, and multi-layering) even though the current-carrying capability varied widely among the samples. The results implied that SLM features were determined by the GB angles not by the property of YBCO films when the dissipation began and the hot-spot appeared on GB.

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1. Cover Sheet

Final Report

(project period 12/15/04 - 06/14/08)

Principle Investigator's name: Chuhee Kwon, Ph.D.

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Agreement number: FA9550-05-1-0037

Title of Project: Characterizing Coated Conductors with Variable Temperature Scanning Laser Microscopy (SLM)

2. Abstract

The grant supported research effort to understand factors limiting current-carrying capabilities in coated conductors (CCs). Three new operating modes of scanning laser microscopy (SLM) were developed under this grant, and total of five SLM modes were utilized for the research. The research found that the increased local-current density (current-crowding) was the main cause for the dissipation and the limiting factor for the current-carrying capacity. It was found in striated CCs that the current-crowding was caused by scratches from sample-handling, localized damages during striation process, or current flow configuration due to specific striation patterns. The other aspect of the research was to understand superconducting dissipation from various YBCO-family films on bicrystal grain boundary (GB) junctions. The samples on 24° [100]-tilt GB showed that the dissipation appeared like "hot-spots" along GB. There was no significant difference in the size and/or the pattern of hot-spots for different YBCO-family samples (regardless of nanoparticle additions, doping, and multi-layering) even though the current-carrying capability varied widely among the samples. The results implied that SLM features were determined by the GB angles not by the property of YBCO films when the dissipation began and the hot-spot appeared on GB.

3. Technical Summary

Experimental Set-up

There are four different modes of SLM operations we have used for this program; variable-temperature SLM (VTSLM), low temperature SLM (LTSLM), thermoelectric SLM (TE-SLM), alternating current SLM (AC-SLM), and pulsed-current SLM (PC-SLM). These modes share the basic experimental set-up shown in Fig. 1.

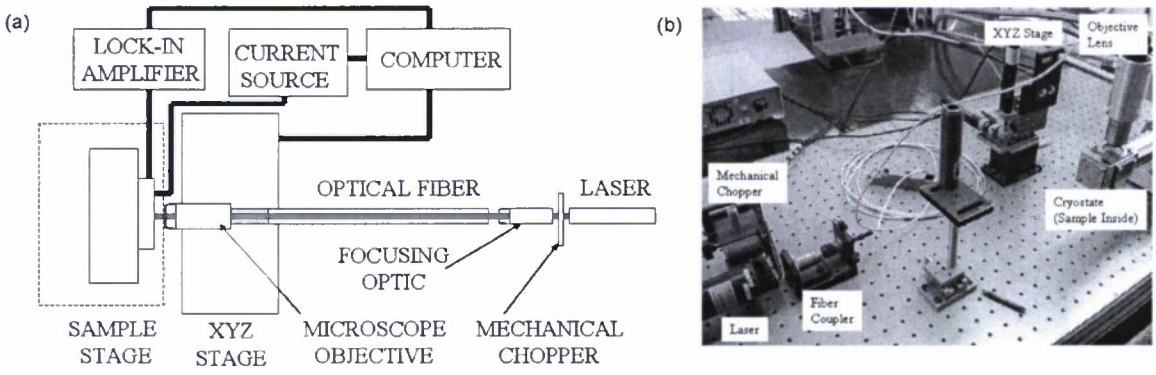

Figure 1 (a) Schematic diagram of our experimental set up. (b) Photograph of the set up.

PC-SLM uses different experimental set-up shown in Fig. 2. More detailed information about the operating procedures of different modes can be found in MS theses listed later in the report.

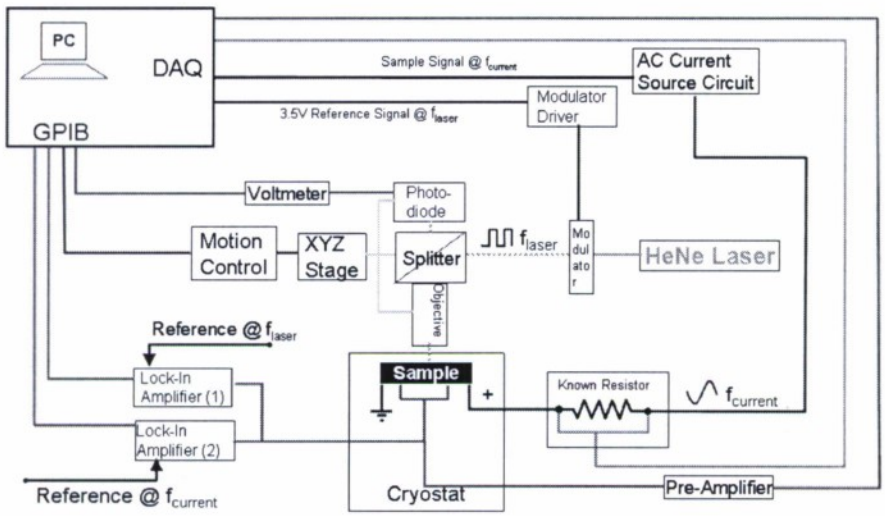

Figure 2. Schematic diagram for PC-SLM experimental set up

Summary of Accomplishments

One of our major accomplishments is to recognize the signature of critical current (I_c) restricting areas. By comparing VTSLM and LTSLM images, we find that (1) lower T_c areas do not necessarily have lower J_c; and (2) the increased local-current density is the main cause for the dissipation in superconducting states and I_c limiting factor. The signatures of increased local-current density (current-crowding area) can be detected in VTSLM images. Our results in striated CCs show that the current-crowding is caused by scratches from sample-handling, localized damages during striation process, or current flow pattern due to specific striation patterns. Our results are reported in the list of publications and the M.S. theses at the end of this report.

We have studied grain-boundary (GB) characteristics of the family of YBCO with 211-nanoparticles, Ca-doping, and multi-layering. TE-SLM worked beautifully in identifying the location of GBs for all samples, and the magnitude of TE-SLM signal was proportional with the grain boundary angles.

We find that the flux-flow in YBCO film is responsible for the dissipation for a lower angle GB. The pattern observed in SLM indicates that the 6° vicinal-cut in the substrate (from YBCO on 6° [100]-tilt boundary $SrTiO_3$ substrate) generates easy path for flux-flow dissipation. Due to the strong dissipation in the film, 6° GB does not appear to be contributing much for the dissipation.

From larger grain-boundary YBCO samples, on 24° [100]-tilt boundary $SrTiO_3$ substrate, GB dominates dissipation in all of them. The emergence of voltage in I-V characteristics is related with the appearance of "hot-spots" along GB in LTSLM images. In some cases, we have

observed step-like I-V characteristics, which may be explained by Fisk steps. Strong correlation is noted between the steps in I-V characteristics and the hot-spot patterns along GB.

So far we have not observed any significant difference in the size and/or the pattern of hot-spots for different YBCO samples from 24° [100]-tilt boundary. This suggests that the superconducting dissipation is similar regardless the addition of nanoparticles, doping, and multi-layering when the sample process is optimized.

Another important aspect of this program was the development of new SLM modes. We demonstrated the feasibility of AC-SLM and PC-SLM. Using AC-SLM, we could obtain images equivalent to regular VTSLM and LTSLM. At this point, we have not found any additional loss/dissipation using AC due to the lower signal-to-noise ratio in AC-SLM and PC-SLM. However, future investigation and development are needed for AC-SLM and PC-SLM.

Summary of M.S. Thesis

1. P. H. Shelby, "VTSLM reveals current distribution around features in striated YBCO".
2. Chooda M. Khanal, "Study of the Local Current Transport Properties of Striated Coated Conductor using Variable Temperature Scanning Laser Microscopy".
3. S. Yoo, "Investigation of Current Percolation Characteristics in $YBa_2Cu_3O_7$ Coated Conductor IBAD Samples with Scanning Laser Microscopy".
4. J. L. Young, "New Operating Modes in Scanning Laser Microscopy".

4. Personnel Supported

PI: Chuhee Kwon, Ph.D.
Graduate student: S. Yoo, Jeremy Young, (C. M. Khanal, P. H. Shelby, K. R. Barraca)
Undergraduate student: Jeremy Young, Ryan James, Meguimi Yamamoto, Samuel Pottish, and Michael Guerrero.
* Students in the parenthesis were not directly paid from the grant, but performed the research as a part of M.S. Thesis

5. Publications

Peer-Reviewed Publications

1. "Mapping the Current Distribution in YBCO Thin Films with Striations", L. B. Wang, M. B. Price, J. L. Young, C. Kwon, George A. Levin, Timothy J. Haugan, and Paul N. Barnes, Physica C **419**, 79 (2005).
2. "The Distribution of Transport Current in the YBCO Coated Conductor with Zipper Striations", L. B. Wang, P. Selby, C. Khanal, George Levin, Timothy J. Haugan, Paul N. Barnes, and C. Kwon, IEEE Transactions on Applied Superconductivity **15**, 2950 (2005).

3. "Investigation of Current Percolation Characteristics in Coated Conductors", L. B. Wang, G. You, K. R. Barraca, K. Waller, J. M. Mahoney, J. L. Young, and C. Kwon, IEEE Transactions on Applied Superconductivity **15**, 3676 (2005).
4. "Local Current Transport and Current Sharing Between Filaments in Striated Coated Conductors with Artificial Defects", C. Kwon, J. L. Young, R. G. James, George Levin, Timothy J. Haugan, Paul N. Barnes, submitted to IEEE Transactions on Applied Superconductivity (2006).
5. "Effects of Local Artificial Defects in Multi-filamentary Coated Conductors with Weak Links", C. Kwon, J. L. Young, and R. G. James, George Levin, Timothy J. Haugan, and Paul N. Barnes, Journal of Applied Physic, **101**, 083908 (2007).
6. "Local Current Transport and Current Sharing Between Filaments in Striated Coated Conductors with Artificial Defects", C. Kwon, J. L. Young, R. G. James, George A. Levin, Timothy J. Haugan, and Paul N. Barnes, IEEE Trans. Appl. Supercond., **17**, 3191 (2007).

6. Interactions/Transitions

a. Participation/presentation at meetings, conferences, seminars, etc.

1. Invited to give a presentation at Air Force Office of Scientific Research Program Review, C. Kwon, "Scanning Laser Microscopy of Striated Samples and CCs", Orlando, FL (Jan. 2005).
2. Talk in American Physical Society Meeting, Los Angeles, CA, B. J. Taylor, D. J. Scanderberg, M. B. Maple, and C. Kwon, "Investigation of vortex-matter states in Y1-xPrxBa2Cu3O7-d" (March 21 – 25, 2005).
3. Talk in American Physical Society Meeting, Los Angeles, CA, P. Selby, C. Khanal, L. B. Wang, and C. Kwon, "VTSLM reveals current distribution around features in striated YBCO" (March 21 – 25, 2005).
4. Talk in Materials Research Society Meeting, San Francisco, CA, C. Kwon, L.B. Wang, P. Shelby, C. Khanal, J.L. Young, G. You, K.R. Barraca, G. Levin, T. J. Haugan, and P. N. Barnes, "Current Flow Characteristics in Striated Coated Conductors", (March 28 – April 1, 2005).
5. Invited presentation at Korea Electrotechnology Research Institute, C. Kwon, "Scanning Laser Microscopy in Coated Conductor Characterization", Changwon, Korea (July 2005).
6. Poster at Southern California Conference for Undergraduate Research (SCCUR) held at University of California – Riverside, J. L. Young. "Enhancing the Capabilities of the Scanning Laser Microscope". (Nov. 19, 2005)
7. Talk in Materials Research Society Meeting, San Francisco, CA, C. Kwon, J.L. Young, G. You, G. Levin, T. J. Haugan, and P. N. Barnes, "Study of Striated Coated Conductors using Scanning Laser Microscopy", (April 18 - 21, 2006).
8. Talk at Stanford-Wisconsin Workshop on Coated Conductors, Palo Alto, CA, C. Kwon, "Local Current Transport and Dissipation in Striated Coated Conductors", (April 24 - 26, 2006).

9. Talk at Stanford-Wisconsin Workshop on Coated Conductors, Palo Alto, CA, J. L. Young, "Enhancing the Capabilities of the Scanning Laser Microscope", (April 24 - 26, 2006).Talk at Applied Superconductivity Conference, Seattle, WA, J. L. Young, R. G. James, C. Kwon, G. Levin, T. J. Haugan, and P. N. Barnes "Local Current Transport and Current Sharing Between Filaments in Striated Coated Conductors with Artificial Defects", (Aug. 27 – Sept 1, 2006).
10. CSULB Physics colloquium, "Investigating Local Properties in Superconductors using Scanning Laser Microscopy", (March 26, 2007).
11. Materials Research Society Meeting, San Francisco, CA, C. Kwon, M. Yamamoto, R. G. James, J.L. Young, T. J. Haugan, and P. N. Barnes, "Sub-gap Structures and Local Inhomogeneity in YBCO Films on Bicrystal Substrates", (April 9 - 13, 2007).
12. Air Force Office of Scientific Research Program Review, C. Kwon, "Update on Scanning Laser Microscopy Effort at CSULB", San Francisco, CA (April 13 - 14, 2007).
13. Talk at MS&T'07 (Material Science and Technology Conference), Detroit, MI (Sept. 16 – 20, 2007), T.J. Haugan, N.A. Pierce, F.J. Baca, M.J. Mullins, T.A. Campbell, M.F. Locke, I. Maartense, A.D. Chaney, P.N. Barnes, H. Hwang, C. Kwon, M.D. Sumption, "Flux Pinning and Grain Boundary Enhancements of YBCO with Nanoscale Multilayer Films"
14. Talk at 13th Japan-US Workshop on Advanced Superconductors, Gifu, Japan, T. Haugan, P. Barnes, T. Campbell, N. Pierce, M. Mullins, F. J. Baca, M. Locke, I. Maartense, C. Kwon, M. Yamamoto, R. James, and J. Young, "Novel Methods of Enhancing Current Transport Across Grain Boundaries of YBCO", (Nov. 9-11 2007).
15. Materials Research Society Meeting, San Francisco, CA, T. J. Haugan, P. N. Barnes, N. A. Pierce, M. J. Mullins, F. J. Baca, T. A. Campbell, and C. Kwon, "Grain Boundary Enhancements of YBCO with Ca-Doping and Nanoparticle Additions", (March 24 – 28, 2008).
16. Talk in American Physical Society Meeting, New Orleans, LA, C. Kwon, M. Yamamoto, S. Pottish, T. J. Haugan, and P. N. Barnes, "I-V Characteristics vs. Spatial Dissipation Maps in YBCO Grain Boundary on Bicrystal Substrates" (March 10 – 14, 2008).
17. Talk in International Cryogenic Engineering Conference 22 and International Cryogenic Materials Conference 2008 (ICEC 22-ICMC 2008), Seoul, Korea, "Local Inhomogeneity at YBCO Graing Boundary with Ca-Doping and Second-Phase Nanoparticle Additions" (July 21 - 25, 2008).

7. New Discoveries, Inventions, or patent disclosures

None

8. Honors/Awards

None